CHARACTERIZATION AND STRENGTH ASSESSMENT OF ALKALI-ACTIVATED IRON ORE TAILING COMPOSITE BRICKS

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by

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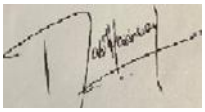

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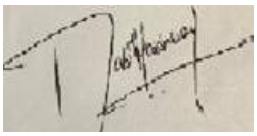

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CONTENTS

SL.NO	CHAPTER DESCRIPTION	PAGE
	ABSTRACT	
1	INTRODUCTION	1
2	LITERATURE REVIEW	2
3	RESEARCH CHALLENGES, GAPS AND LIMITATIONS	5
4	OBJECTIVES	6
5	TOOLS AND METHODOLOGIES	7
6	ACCOMPLISHMENT OF RESEARCH WORK	8
7	RESULTS AND DISCUSSIONS	14
8	CONCLUSION	26
	BIBLIOGRAPHY	28
	PUBLICATION S	30
	ANNEXURE	31

ABSTRACT

The current research presents the methodology for manufacturing the bricks which are eco friendly and competent to fit in the present day dynamic market. Iron Ore Tailings (IOT) which is teamed as waste by the mining industry is been studied in the current research for manufacturing the bricks. Bricks were produced using IOT, obtained from iron ore mines in southern part of India. The research is based on the Alkali-activation method of developing the IOT bricks, which is proven to be most energy conservation method of production, as it reduces the greenhouse gas emission unlike in conventional method of manufacturing the bricks. India is a country which is abundant in iron ore deposits, which intern has lead to extensive mining activities resulting in increase in waste generation i.e., IOT. The current practice of disposing this waste is to dump in the dumping sits/dam near mining area. These tailings are highly potential to contaminate the surrounding environment. Hence, utilization of IOT in production of bricks will reduce the burden of waste disposal for the mining industry and also by utilizing the IOT in preparing bricks will bring down the exploitation on the natural raw materials in making the conventional bricks. In the present research different brick composites were synthesized with Ground Granulated Blast Furnace Slag (GGBS), Flyash and IOT with sodium silicate solution. All the raw materials are examined by X-ray fluorescence (XRF), X-ray diffraction (XRD), Scanning electron microscope (SEM) and Particle size analysis (PSA). Different tests were conducted on the developed IOT bricks to determine its strength and durability as per the Indian standards. The developed IOT bricks processed the maximum compressive strength up to 18.45N/mm^2 with minimum water absorption of 12.6%. Also alternate wetting and drying test on the bricks was conducted to know the long term durability as per the Brazilian standards. All the results obtained were validated through microstructure analysis of the developed product. Further, the study was focused on determining the compression strength of the alkali-activated IOT brick prisms in Combination with different mortar strength. Finally it was concluded that more than 50% of IOT can be used in combination with GGBS and flyash along with sodium silicate solution as an alkali activator to prepare high-quality bricks at the room temperature curing conditions.

Key words: Iron Ore Tailings, Sodium silicate, GGBS, Flyash, Compressive strength, water absorption, Durability, masonry prism

1. INTRODUCTION

India is the nation which is abundant in its natural recourses especially in mineral ore. The ore deposit in the country is so huge that it has lead to extensive mining work. The mining sector of the nation is contributing enormously towards the economic development of the country. The mining industry is nearly contributing 1.63% of the nation's Gross Domestic Product (GDP) [1]. On an average India is producing around 200 million metric tonnes of iron ore every year [2]. This large quantity of iron mining in India is resulting in huge amount of Iron Ore Tailings (IOT) generation. IOT is one of the wastes produced during the beneficiation of iron ore. Figure.1 shows the IOT generation process. The amount of IOT generated and the properties of IOT generated varies from one mine to another mine as it depends on the method adopted for the beneficiation. It is calculated by few researchers and mining industry that production of one tonne of iron ore will lead to two tonnes of IOT generation as waste [3]. The general practice of the mining industry to dispose IOT is to deposit IOT in the dumping sites, the continuous disposal of IOT in the dumping sites is leading to environmental problems, it is known that IOT contains heavy meals which are hazard to natural soil and water. When there is a rain theses heavy metals will be washed away by rain water and can contaminate the nearby water source and will cause danger to animal, vegetation and human health [4]. Also long term disposal of IOT will lead to loss of fertility of the natural soil resulting in loss of vegetation, soil erosion, landslides, pollution etc [5, 6]. Hence, one of the solutions can be converting IOT into some useful product like brick. Soil being one of the oldest construction material, it is been used extensively for many purpose in the construction industry, the extensive use of soil is causing ecological imbalance in the nature. Using IOT for making bricks may bring down the exploitation of the virgin soil in construction sector which intern will reduce the carbon footprints. IOT is studies by various researchers for its different application in construction industry; IOT is utilized in production of different types of concrete, production of roof and floor tiles, and also in soil back filling as per the literature. Also there are studies where IOT is used in brick production by cementing method, Geopolymerization and conventional firing method. The study and expansion programs were be carried out at the Department of Civil Engineering, CHRIST (Deemed to be University).

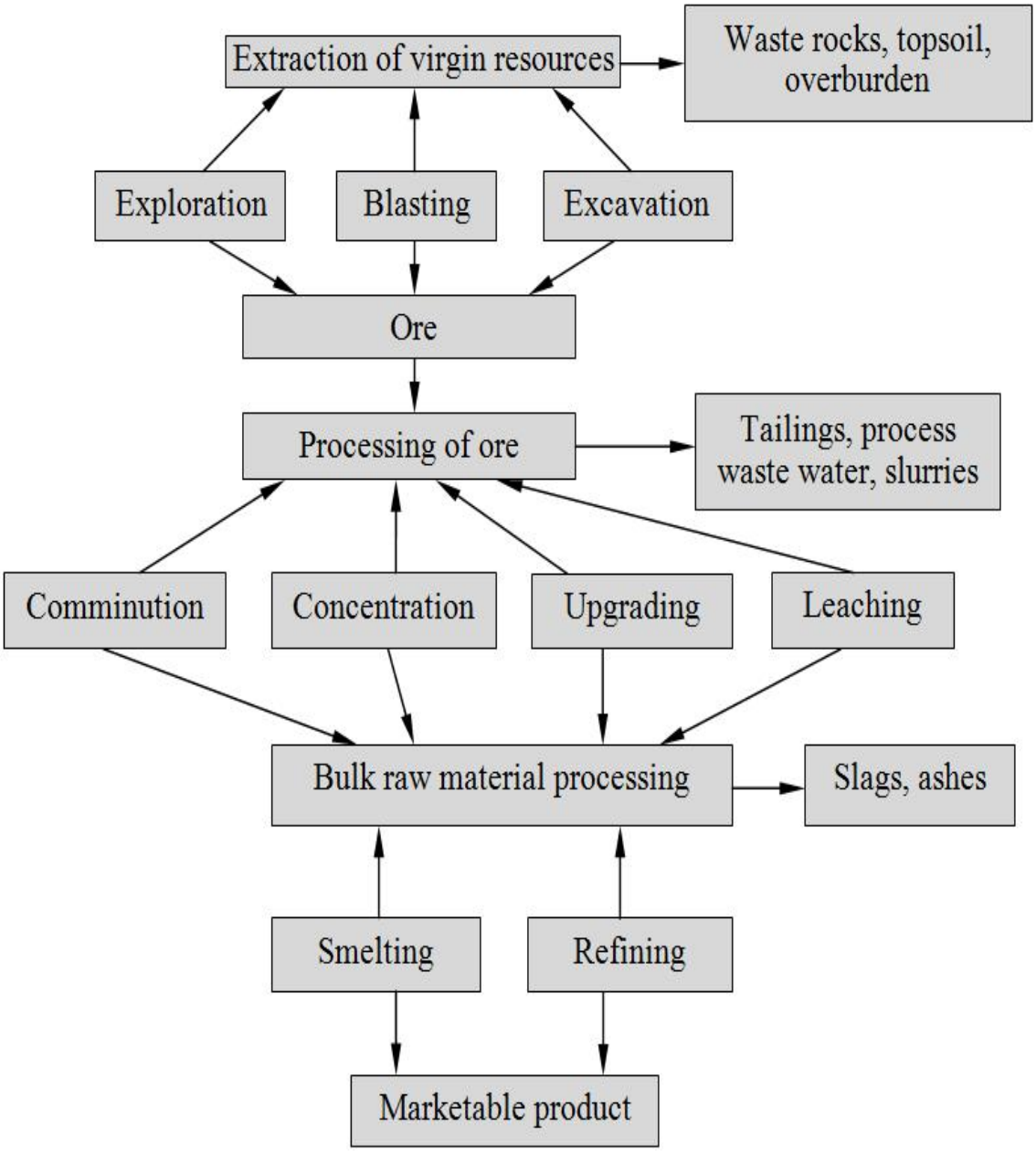


Figure.1: Mining processes and waste generation (*Francis et al., 2015*)

2. LITERATURE REVIEW

Ullas et al. (2010) studied the mine waste as an substitute to river sand in producing the clay blocks. The river sand was replaced by 25,50and 100% with mine waste in along with clay in production of blocks. All the blocks developed were of good characteristics. Conclusion was made that use of mine waste in blocks will increase the water absorption of the blocks.

Goaxiang et al. (2012) studied the influence of the sintering temperature in production of sintered IOT bricks. Clay, coal refuses, betonite and 40% IOT was used in the brick preparation. It was concluded that high strength of IOT brick upto 128Mpa can be achieved at sintering temperature of $1100^{o}C$.

Lianyang et al. (2012) reviewed the use of IOT in production of bricks. It is stated that although there are many researches have been conducted in utilizing mine waste for production of bricks by different methods but yet commercializing of the product is limited. The probable reasons are related to the potential contamination from the waste materials used, the absence of applicable standards, and the sluggish acceptance of IOT-based bricks by the industry and public and poor government policies related to waste recycling.

Saeed et al. (2013) studied the environmental aspects of the geopolymer based IOT bricks, mainly the paper was concentrated on durability and leaching properties of the bricks. Bricks were immersed in the pH = 4 and 7 solutions for varying time period. Microstructural analysis was performed to study the phase formation of IOT bricks after immersion in alkaline solution. FRDM model was used to study the leaching behaviour of bricks. It was observed that there was strength loss after immersion. Weight loss and water absorption was minimal. From leaching analyses it was observed that the heavy metals are effectively immobilized in the geopolymer IOT bricks.

Francis et al. (2014) studied the effects of initial setting time, curing temperature and time by adding the sodium silicate in powder form to IOT to form geopolymer bricks. Water absorption, compressive strength and durability were studied. 50.53Mpa strength was achieved for the optimum mix. Cost analysis was also performed and revelled that the IOT geopolymer bricks were cheaper when it is compared to the commercial conventional clay bricks.

Prahallada et al. (2014) made an attempt to study the suitability of IOT in the developing bricks by using cement. varying percentages of cement was used for the brick stabilization. compressive strength, water absorption and erosion resistance were establish. The results show that the stabilized blocks of IOT with 7% replacement of IOT with cement gave the highest strength.

Chuanmeng et al. (2014) studied utilizing low-silicon IOT in production of fired bricks. Fly ash was added with IOT. The bricks were prepared and fired, and then the sintering shrinkage, weight loss on ignition, water absorption, apparent porosity, compressive strength, phase compositions and microstructure of the samples were investigate. It showed that the firing temperature and flyash significantly alters the bricks properties.

Shreekant et al. (2015) attempted to prepare bricks using IOT, fly ash and cement. Bricks were prepared and tested for its feasibility for usage in building industry. The results of the study reveals that mixture with 70% IOT, 15 % flyash and 15 % cement gives the minimum required strength and water absorption for minimum curing days.

Balarabe et al. (2015) studied the combination of sawdust ash (SDA) and IOT with clay to prepare fired bricks. 5%SDA found to be the optimum of SDA, this percentage is then mixed with 10, 20 and 30% of IOT in order to get the best mixture. water absorption, shrinkage and compressive strength tests were conducted on fired clay bricks at variable admixture content. The results show that Soil with 5%SDA and 30%IOT give the best performance.

Nagaraja et al. (2016) conducted an exploratory study to prepare bricks using Mine Spoil Waste (MSW), quarry dust and stabilizers (Cement and lime). Attempts made in the study shown that compressive strength of blocks was more than 5 MPa at 6 months of ageing.

Tatheer et al.,(2021) prepared 40 concrete block masonry prisms and tested with three different types of mortars, Failure modes, compressive strength and stress-strain curves were examined. It showed that the lower grade mortared prisms failed by mortar crushing, whereas the other mortared prisms mainly failed by tensile splitting in the blocks.

Na Zhang et al,.(2021) presented the use of IOT in construction and building materials, namely production of cementations materials, preparation of bricks and preparation of concrete. It was suggested that low-silica IOT can be used to prepare bricks by firing and also geopolymerization process. It was found that about 40% IOT can be replaced for natural materials in making bricks.

3. RESEARCH CHALLENGED, GAPS AND LIMITATIONS

Based on the literature review it is found that space required for the discarding of the IOT in the coming days will be a major challenge for the mining industries. There are also environmental contamination issues and the likelihood of the disposed IOT causing acid mine drainage (AMD) and leaching of metals from IOT will harm folks and the surroundings. In order to eliminate this problem, there is a necessitate to discover and institute a sustainable recycle potential for IOT generated in India. To augment IOT consumption, there is the necessitate to bring out more research in the concerned area to find applications that will ensure grate volume of IOT utilisation. At present, utilization of IOT in its application is very poor. Some attempt to utilise the IOT will decrease the volume of IOT available and will intern bring down the environmental effects. Based on the research conducted by various researchers it is said that IOT has the potential application in Bricks, which is the most common building material used so far. It is observed that the bricks developed using IOT shows a very good results as per IS specification when compared to conventional clay bricks, very limited studies are made to give a general methodology for manufacturing bricks with the particular characteristics of IOT. There is very low available literature on alkali activated IOT bricks with sodium silicate alone and also the studies on the compressive strength of IOT masonry prism and very limited.

4. OBJECTIVES

Based on the available research and gap identified the research will have the following objectives

1. Detailed investigation on physico -chemical characteristics of IOT.
2. Evaluation of strength and durability properties of alkali-activated IOT bricks.
3. Comparative study of alkali-activated IOT bricks with Indian standards.
4. Evaluating the compressive strength of alkali-activated IOT brick masonry prism with varying mortar strength

5. TOOLS AND METHODOLOGIES

5.1 Material selection

The raw materials are selected as follows

- IOT from BMM ISPAT mines, Ballery
- GGBS form local market
- Class-F flyash from Raichur thermal power plant

5.2 Material Characterization through sampling

Sampling and characterization of material will be done at different periods to better understand the possibility of material variability.

Tests on raw materials includes

(i) Particle size analysis as per IS 2720 (part4) 1985.

(ii) Specific gravity as per IS 2070 (partIII/sec1) 1980.

Characterization of raw materials also includes chemical composition, mineralogical composition (XRD) and textural behaviour(SEM).

5.3 Composite preparation with varying proportions of IOT and clay

This task will be performed in laboratory to determine the optimum proportions of IOT required for composite formation by stabilizing method and alkali activation method.

5.4 Evaluation of strength- Brick and Prism

Strength will be assessed by conducting various tests on composites according to BIS and ASTM standards to evaluate the behaviour under various loading conditions.

5.4.1 Individual unit

(i) Water absorption as per IS 3495:1992 Part2.

(ii) Compressive strength as per IS 3495: 1992 Part1.

5.4.2 Prism Test

Compressive Strength of Masonry by Prism test will be conducted on the best performing composites with staking configuration. IS 1905-1987 gives the procedure for testing of masonry prism for determination of compressive strength of masonry.

6. ACCOMPLISHMENT OF RESEARCH WORK

6.1 Characterization of raw materials

Raw materials used in the present research

1. IOT – BNM Ispat Mines, Bellary
2. GGBS – Local market
3. Flyash – Raichur thermal power plant

Characterization is divided into two categories

1. Physical characters
2. Chemical composition

6.1.1 Iron ore tailings

Iron ore tailings (IOT) are the waste materials that obtained from after the extraction of iron from the mine ore. After extraction process the residue is discarded as a waste material. Generally iron ore tailings contain 20-40% of iron is considered as waste.. For this research work IOT used was from BMM ISPAT mines located in Bellary in Karnataka. The table1 and table2 shows the physical and chemical composition of IOT respectively.

Table1: Physical properties of IOT

Properties	**Results**
Specific Gravity	3.20
Optimum Moisture Content	9.6%
Maximum Dry Density	2410kg/m3
Liquid Limit	26%
Plastic Limit	15.5%
Plasticity index	9.2%

Table2: Chemical properties of IOT

Constituents	**(%)**
Silica	30.37
Alumina	12.43
Titanium Dioxide	3.96
Ferric oxide	46.33
Calcium Oxide	3.88
Magnesium Oxide	1.68
Potash	0.25

It can be observed from table2 that the silica and calcium content is very less compared to ferric oxide and titanium dioxide contents.

6.1.2 Ground Granulated Blast Furnace Slag (GGBS)

Ground granulated blast furnace slag (GGBS) is obtained by rapidly chilling the molten ash from the furnace with water. In this research GGBS act as a binder. For this work JSW GGBS available in local market with the below properties is used. Table3 shows the properties of GGBS used in the current research.

Table 3: Properties of GGBS

Parameters	**% by Wt**
Silica	32.50
Alumina	17.54
Titanium Dioxide	0.85
Ferric Oxide	1.36
Calcium Oxide	37.10
Magnesium Oxide	7.34
Sodium Oxide	0.57
Potash	0.31
Specific Gravity	2.65
Fineness Modulus	2.83

As shown in table 3, Since (Cao+Mgo)/Sio_2 = 1.29, it meets the requirement of BS146-1996, and the sulphur content is 1.9% which satisfies the ASTM-C989 requirements. GGBS used in present study also satisfied the ASTMC989 fineness criterion with less than 20% retained on a 45 micron sieve.

6.1.3 Fly ash

Flyash used in the current research was obtained from Raichur thermal power plant. The properties of the flyash is tabulated in table4.

Table 4: Properties of flyash

Parameters	**% by Wt**
Silica	59.18
Alumina	21.48
Ferric Oxide	3.70
Calcium Oxide	6.42
Magnesium Oxide	2.22
Sodium Oxide	1.72
Potash	1.90
LOI	2.48
Specific Gravity	2.28
Fineness Modulus	2.36

For flyash, the combined silica, alumina and ferric oxide was 83.7% and LOI was 2.48%, there for it is classified as class-F according to ASTMC618. Fly ash also satisfied the fineness criterion of ASTMC618 with 70.5% of flyash particles finer than 45 micron sieve.

6.1.4 Lime

Lime used in this study was hydrated lime acquired from the local market. Fifferent properties of the lime is tabulated in table5.

Table 5: Properties of Lime

Parameters	**% by Wt**
Silica	1.54
Alumina	1.17
Ferric Oxide	0.02
Calcium Oxide	0.50
Magnesium Oxide	0.15
Calcium hydroxide	96.62
Specific Gravity	2.10

6.1.5 Scanning Electron Microscope (SEM)

SEM is a type of electron microscope that produces the fine molecules into high quality images. SEM uses electrons that interact with atoms in the sample.SEM can give resolution

more than 1 nanometer. The advantage of SEM is to identify the shape and texture of the particles. The electron beam is scanned in a raster scan pattern and position of beam is combined with the detected signal to produce an image. It is evident from figure3 that Rough texture with slight porous surface were observed in IOT, Smooth surface angular particles also absorbed fine GGBS particles adhere to larger size particles in GGBS. SEM micrograph of flyash exhibited spherical particles of different sizes. It also shows the cavities of larger flyash particles occupied with very fine flyash particles. Flyash in this study exhibited the typical nature of cenospheres.

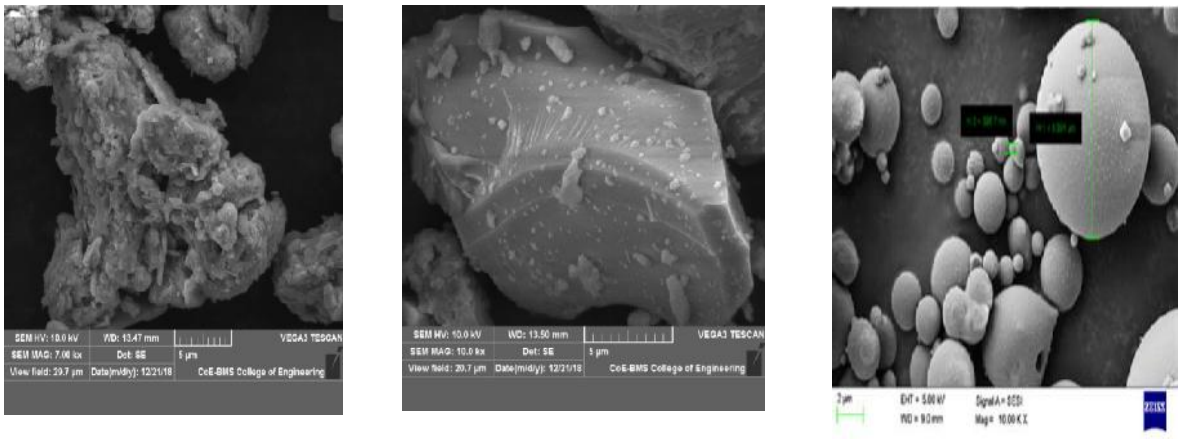


Figure.3: SEM images of IOT, GGBS and Flyash respectively

6.1.6 X-Ray Diffraction

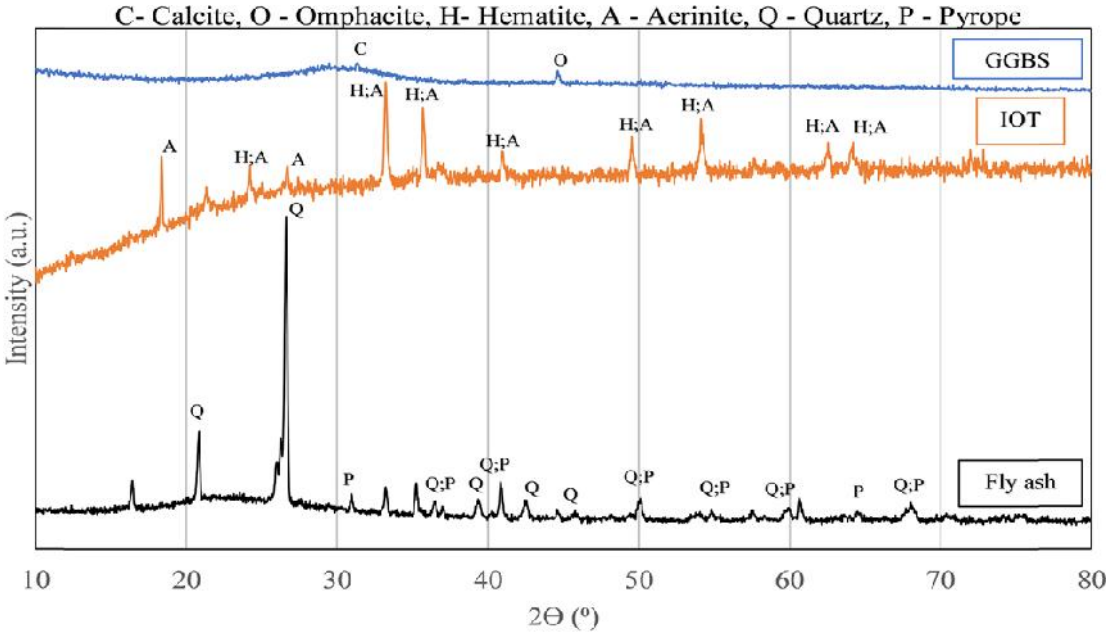


Figure.4: XRD patterns of raw materials

As indicated in figure 4. The major mineral phases of IOT were hematite (Fe2O3) and aerinite, while the major mineral phases of fly ash were quartz and pyrope and for GGBS it was calcite and omphacite, respectively.

6.1.7 Particle size distribution

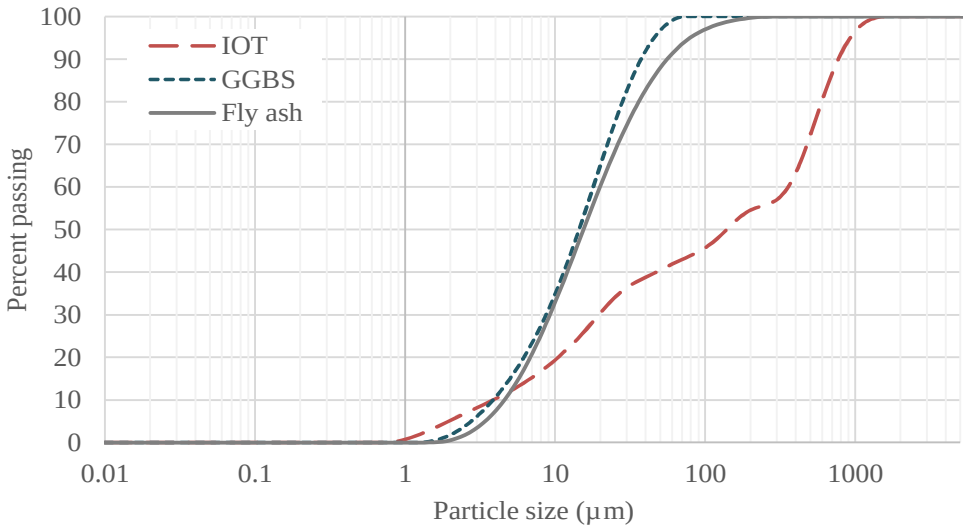


Figure.5: Particle size distribution of raw materials.

For chemical activation of the raw materials the particle size plays a major role, and the finer the particle size higher is the reactivity. The PSA was performed using Malvern Instruments Mastersizer MS2000 and its results are shown in Figure 5. It is clear that GGBS is the finest followed by fly ash and IOT, and they are 95%, 85%, and 39% finer than 45 µm, respectively. Also, it is interesting to see that IOT particles are not uniform in size, since there are significant particles larger than 100 µm, while a good percent of IOT particles is finer in size.

6.2 Grade Designation

Two set of mix proportions were made. First set of mix designs was by made by conventional method without firing consisting of IOT, GGBS, Lime and water and second set was by alkali activation method, consisting of IOT, GGBS, Flyash and sodium silicate were designated as follows and the batch size was fixed to 50kg, The mix type and the compositions are presented in table 6 and 7. Preparation of building blocks, with mix/block ID designation as 42I-44 G, which represents 42% IOT and 44% GGBS, respectively for compressed unfired IOT bricks and the developed alkali-activated brick with IOT is denoted as AABI followed by the percent of IOT represented numerically. Therefore, AABI40

indicates bricks with 40% IOT. The amount of liquid alkaline activator was kept constant at 8% for all the mix types. The extra water that was determined based on trials was necessary to achieve a consistent mix for each of the different brick compositions.

Table 6: Mix Types – Compressed unfired bricks

Mix type	IOT	GGBS	Lime	Water
	%	%	%	%
42I-44G	42	44	4	10
52I-35G	52	35	4	9
62I-26G	62	26	4	8
42I-17G	72	17	4	7
72I-7G	82	7	4	7

Table 7: Mix Types - Alkali activated bricks

Mix type	IOT	GGBS	Flyash	Water	Sodium Silicate	Molar ratios (mol/mol)				
	%	%	%	%	%	Si/Al	Na/Al	CaO/Al_2O_3	CaO/SiO_2	Na_2O/CaO
AABI40	40	21	21	10	8	4.37	0.20	1.26	0.28	0.16
AABI50	50	17	17	8	8	4.38	0.19	1.10	0.25	0.17
AABI60	60	13	13	6	8	4.38	0.17	0.95	0.22	0.18
AABI70	70	9	9	4	8	4.38	0.16	0.82	0.19	0.19
AABI80	80	5	5	2	8	4.39	0.14	0.70	0.16	0.20
AABI90	90	0	0	2	8	4.40	0.13	0.56	0.13	0.23

Note: Weight calculations are based on respective densities of raw materials

7. RESULTS AND DISCUSSION

7.1 Density test

This experiment was conducted on IOT brick sample to know the density of brick. The density was calculated by using the formula.

$$\text{Density of the brick} = \frac{Weigt\ of\ the\ brick}{volume\ of\ the\ brick}$$

For conventional fired bricks or earthen blocks, the density ranges between 1800 and 2000Kg/m^3. However, in the present study, introduction of IOT exhibited slightly higher density, which was in the range of 2000 to 2400 kg/m^3 for various block types The density of different composition of brick is given in table8.It is observed that the density is increasing as the IOT content and sodium silicate is increasing in the composition.

Table 8: Density of Brick

Mix Type	**Compressed unfired bricks density (kg/m^3)**	**Clay brick density (kg/m^3) As per Indian standard IS-3495**
42I-44G	2150	1800 to 2000
52I-35G	2160	
62I-26G	2170	
42I-17G	2190	
72I-7G	2200	
Mix Type	**Alkali Activated bricks density (kg/m^3)**	
AABI40	2012	
AABI50	2076	
AABI60	2090	
AABI70	2362	
AABI80	2382	
AABI90	2405	

7.2 Compressive strength of bricks

Compressive strength of brick is conducted to know the how much load is being taken by brick under compression, compressive testing machine (CTM) was used for experiment process of compression tests. Compressive strength of brick was conducted as per IS-3495 part-1, 1992. The brick was placed carefully in compressive testing machine and steel plates are kept top and bottom of brick. The frog of brick was filled with sand or cement mortar for uniform load. The load was applied gradually at uniform rate of 14 N/sq.mm per minute till the failure occurs. It was calculated using the formula.

$$\text{Compressive strength} = \frac{Load\ at\ failure}{surface\ area\ of\ the\ brick}$$

Table.9 shows the compressive strength of various blocks prepared. As seen, the performance of blocks improved with increase in GGBS content, especially after 28 days of curing. The average compressive strength of 7.7 MPa for 42I-44 G was the best among all the unfired compressed block types. Such improvements can be attributed to the complex reaction mechanism of GGBS and lime with IOT. Generally, when GGBS and lime are blended with soil, it causes a distinct reaction. This includes an exothermic reaction causing rapid ion exchange and a much slower pozzolanic reaction, which results in soil improvement and stabilization, respectively. Furthermore, there is possibility of calcium ion exchange from lime and GGBS with metallic ions in the IOT. Also, slower reaction of calcium with silica and alumina in IOT forms much stable silicates and aluminates providing better strength and durability over time. Among alkali activate bricks As seen, brick type AABI40 showed the highest average compressive strength of 18.45 N/mm^2 when compared to all other brick types. Further, the strength reduction is marginal for brick types AABI50 and AABI60 when compared to AABI40. However, there is a substantial reduction in strength for brick types AABI70, AABI80, and AABI90 when compared to AABI40. This is true because the reactive nature of IOT depends on the amount of silica and alumina species available, and further, dissolution and polycondensation are improved with an increase in curing temperature. Since IOT in the current study hasa low amount of silica and its complex nature with a high amount of Fe_2O_3 content, results in IOT's contribution towards strength development to be minimum. Thus, itcausesa decrement in strength with an increase in IOT content in the brick. Also, it is interesting to notice that the addition of flyash and GGBS was effective in improving the compressive strength of bricks with a high proportion (i.e., 40% to 60%) of IOT with low silica and thus suggesting the prospective to improve the recyclability of IOT in the brick industry.

Table 9: Compressive strength of IOT bricks

Mix Type	**Compressed unfired bricks compressive strength (N/mm^2)**	**Clay Brick compressive strength (N/mm^2) As per Indian standard IS-3495**
42I-44G	7.7	3.5 to 12.5
52I-35G	6.8	
62I-26G	6.4	
42I-17G	5.9	
72I-7G	5.7	
Mix Type	**Alkali Activated bricks compressive strength (N/mm^2)**	
AABI40	18.45	
AABI50	16.55	
AABI60	16.07	
AABI70	13.3	
AABI80	11.6	
AABI90	7.6	

7.3 Water absorption Test

Water absorption test is conducted as per IS-3495 part-2, 1992. The test was conducted immersing the brick in water water for 24 hours and as per IS code water absorption of brick should not be more than 20 percent of water by its weight. Table. 10 shows the water absorption in different composition of IOT bricks. Water absorption was calculated using the formula.

$$\text{Water absorption} = \frac{Dry\ brick - wet\ brick}{Dry\ brick} X100$$

As seen in table.10, the best performance in compressed blocks was observed for 42I-44 G, which is similar to that of compressive strength results. This can be attributed to the presence of lime and GGBS, which improves the pozzolanic reaction of such system and leads to the

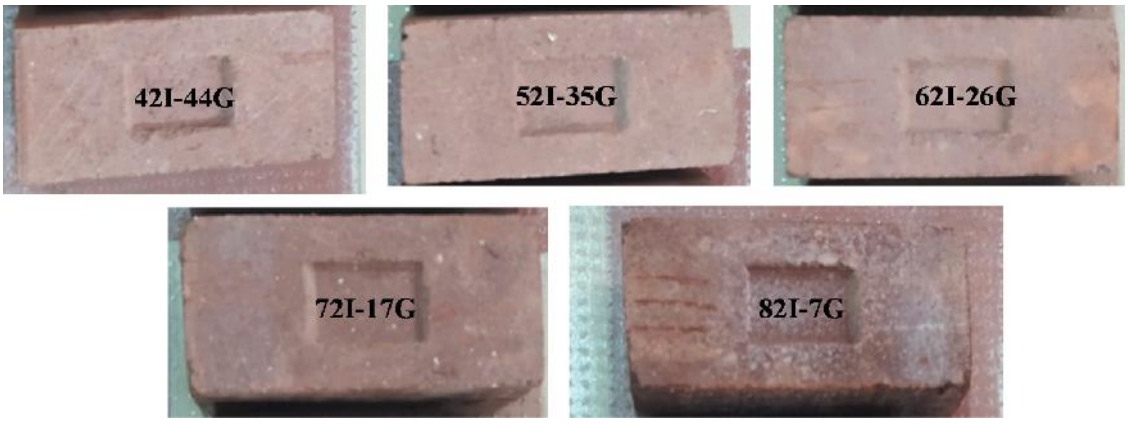
formation of alumino-silicates. Furthermore, for the blocks with higher GGBS, exothermic reaction initiates a faster dissolution of amorphous silica in IOT and GGBS. This also gives rise to generation of pozzolanic reaction products, which fill up the pores and make such blocks denser, and further reduce its water absorption. In alkali activated bricks, the brick type AABI40 showed the least average water absorption of 12.6% and meet the requirements of IS 1077 and CNS 382 for first-class brick. Similarly, the brick type AABI90showed the highest average water absorption of 18% and meet the requirements of IS 1077 and CNS 382 for second-class brick. Such findings indicate that with an increase in IOT, the porosity of bricks increases, primarily due to less reactive products formed during the synthesis process. Also, increasing flyash and GGBS content reduces the voids between the IOT particles due to filling-ability by fine particles, and reactive products formed due to synthesis, and thus reducing the water absorption of the bricks. Finally, all the prepared blocks demonstrate water absorption within the permissible limits of IS 1077.

Table 10: Water absorption of IOT bricks

Mix Type	**Compressed unfired bricks water absorption (%)**	**Clay Brick water absorption (%) As per Indian standard IS 1077**
42I-44G	13	<20
52I-35G	17	
62I-26G	18	
42I-17G	18	
72I-7G	19	
Mix Type	**Alkali Activated Bricks water absorption (%)**	
AABI40	12.6	
AABI50	14.6	
AABI60	16.5	
AABI70	17.47	
AABI80	17.5	
AABI90	18	

7.4 Efflorescence Test

Efflorescence test was conducted as per IS-3495-part-3-1992. Initially the cured brick was taken kept in a tray and water is to be poured, the brick was immersed in water up to 25mm depth. If the brick absorbs total water and once again water was poured upto 25mm depth of brick. Maintain the leave of water for 24 hours and take it out keep it in shade. Observe, any efflorescence formed on the bricks. Figure.6 shows the efflorescence test results of compressed unfired bricks and alkali activated bricks, it was observed that there was slight or no efflorescence. Efflorescence is attributed to the deposit of the soluble salts on the brick surface. It is very common when there is presence of water-soluble salt, water and porous medium in the brick. Most of the blocks did not show any sign of efflorescence, except for 82I-7 G which showed mild efflorescence. This suggests that prepared blocks were compact with minimum pores, which avoid the movement of the soluble salt through such medium. It also assures the potential of such blocks in practical applications and further suggests the positive interaction between GGBS, lime and IOT in developing much stable and durable building blocks. As observed, the increase in IOT content has caused higher efflorescence, and therefore, brick type AABI90 shows a heavy deposit of salts on the surface, while brick type AABI40 shows no deposit of salts on the surface. This was expected since geopolymer binders with less reactive silica and alumina species suffer from efflorescence, due to surplus sodium oxide remaining unreacted which can easily transport with moisture through the brick pores to the surface. Furthermore, an increase in flyash and GGBS in the brick improves the alumina content which enhances the crosslinking in the binder phase and hinders the mobility of alkalis, and therefore, brick type AABI40 showed no signs of efflorescence.



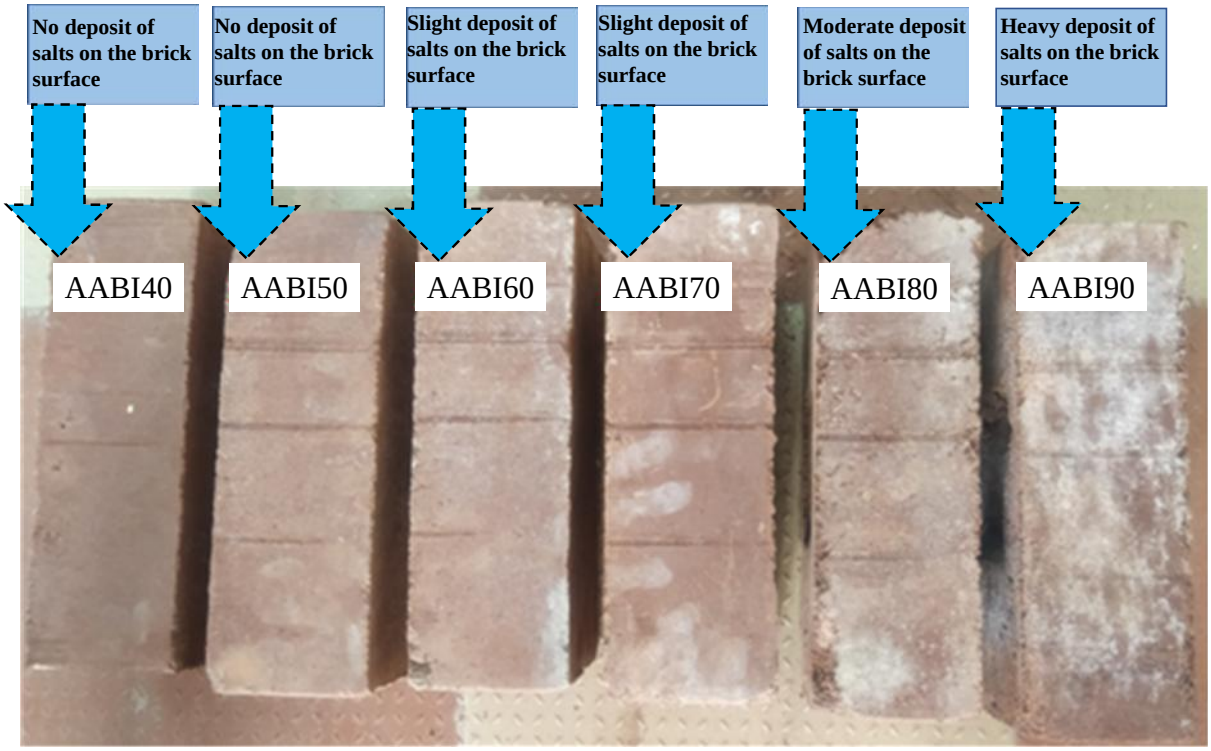

No deposit of salts on the brick surface
No deposit of salts on the brick surface
Slight deposit of salts on the brick surface
Slight deposit of salts on the brick surface
Moderate deposit of salts on the brick surface
Heavy deposit of salts on the brick surface
AABI40
AABI50
AABI60
AABI70
AABI80
AABI90

Figure 6: Efflorescence test results

7.5 Microscopic analysis

In alkaline activation of geopolymers, it is quite common to obtain zeolite species such as analcime, sodalite, natrolite, nepheline,among others. However, the type and quantity of these phases depend on the nature of precursor material, calcination temperature, and alkaline sources. In this study, such crystalline phases were not observed as noticed in Figure 7, and this might be possible since the bricks were cured at room temperature. Further, the silica and alumina oxides of IOT might have partially decomposed and not been distinctly identified by XRD due to their disordered structure. Besides, it also shows that one-part alkali-activated mixes lead to less formation of hydration products when compared to normal alkali-activated mixes. Also, it is interesting to observe that the addition of GGBS has improved the strength of bricks. This improvement can be explained due to the formation of the reaction product C-S-H due to the alkaline activation of GGBS. Further, C-S-H is mostly observed to appear in the hump at 2Θ range of 25^0 to 35^0, and particularly, a peak centered around 29^0 is dominated by this phase. As noticed in Figure 13, brick types AABI40 and AABI50 exhibited a peak at 29^0, suggesting the formation of C-S-H, and thus positively contributing to the strength and durability properties of these bricks.The SEM micrographs of the bricks are shown in Figure 8 . It is evident that the best microstructure is observed for brick type AABI40with a dense matrix of reactive products that minimizes the pores, and holds the

constituents together, which further improves the resistance of brick to external forces. Also, as the content of IOT increases in the bricks, the formation of reactive products decreases and more voids start to appear. For instance, in brick type AABI90, there are many unreacted IOT particles, and therefore large voids were noticed in the micrographs, suggesting the poor performance of these bricks to external forces. Finally, unreacted flyash particles were also noticed which occupy the space between IOT particles and further help reduce the voids in the brick.

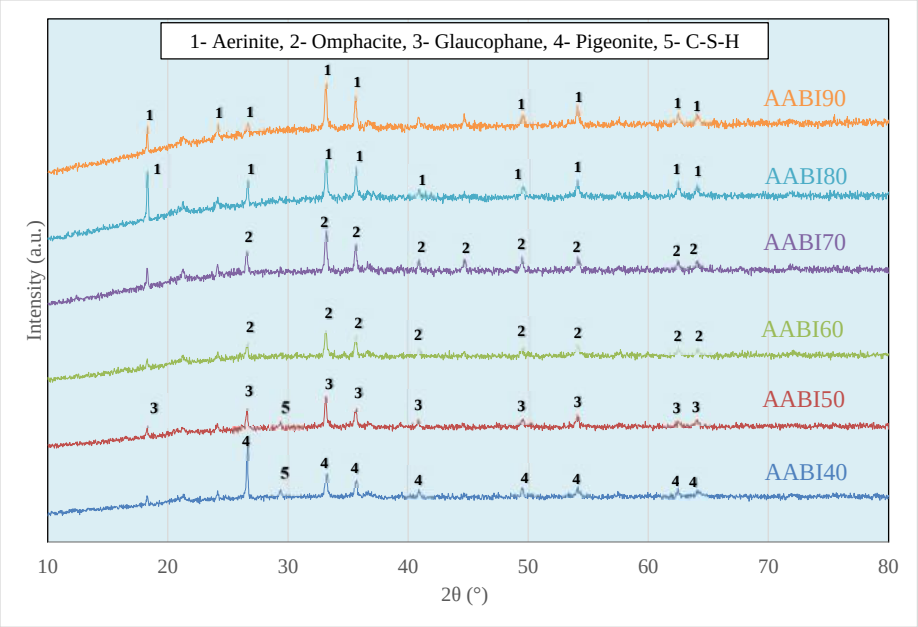
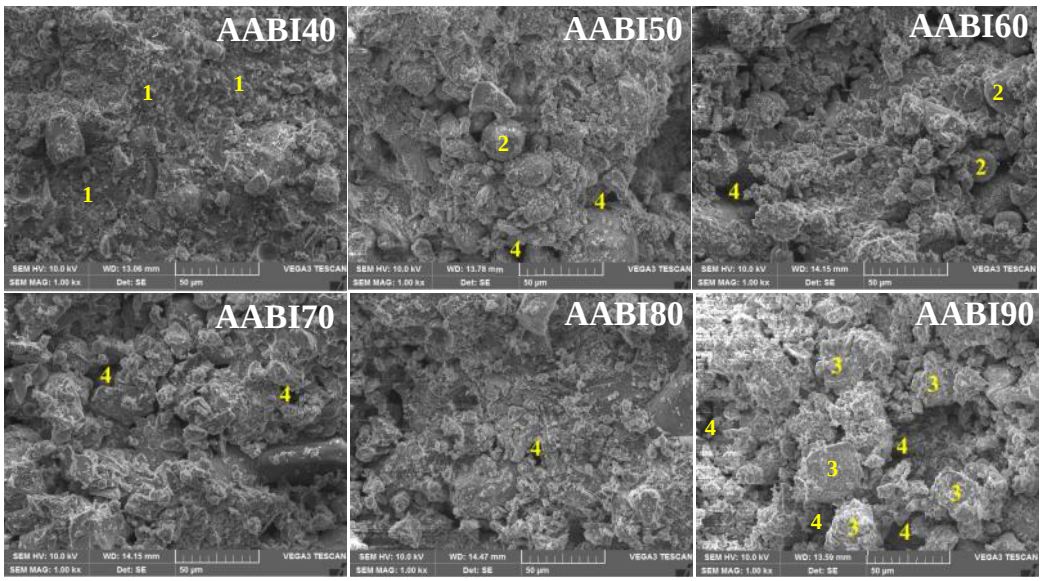


Figure 7: XRD patterns Alkali activated bricks



Note: Numbers in the figure indicate, 1 – dense microstructure, 2- Unreacted flyash particles, 3 – Unreacted IOT particles, 4 - Voids

Figure 8: SEM micrographs of alkali activated bricks

7.6 Durability test

The durability of bricks was assessed using the accelerated ageing method which consists of a cyclic test of wetting and drying. The details of this test have been discussed in NBR 13544 [22] and a similar test was carried out to evaluate the durability properties of soil-cement bricks with iron ore mining waste [23]. This test was performed for seven cycles. Each cycle consists of complete immersion of brick in clean water for 5 h (i.e., wetting cycle) and subsequent drying in an oven at 70 ◦C for 42 h (i.e., drying cycle). After each cycle, three brick specimens were tested for compressive strength. The brick ageing by alternate wet and dry cycles is a good way to mimic the resistance of the bricks to changing climatic conditions. Since such exposure conditions are expected when bricks are used in real-life situations. Therefore, the outcome of this test will be ideal to assess the durability of alkali-activated bricks with IOT. Fig. 9 shows the compressive strength of bricks for one to seven cycles (C1–C7) of alternate wetting and drying, and the corresponding reduction in strength with respect to strength without conditioning is shown in Fig. 10. As seen, the increase in IOT has reduced the resistance of bricks to ageing, and therefore, brick type AABI40 outperformed all other bricks. This is attributed to the contents of IOT in brick which influence the synthesis process. As the IOT content increases, the reactive products decrease, apparently due to the less reactive nature of IOT and thus it results in larger pore size in the bricks. As a consequence, during the wetting cycle, water can easily penetrate and when drying easily exit, due to large pores which act as a channel for the movement of water. Therefore, brick type AABI90 has suffered from heavy loss after cyclic test and a maximum reduction of 48.03% in compressive strength was observed as seen in Fig. 9. Furthermore, it is interesting to observe that with the addition of fly ash and GGBS resistance to cyclic test has improved and a minimum reduction of 14.69% in compressive strength was observed for brick type AABI40 with 40% IOT, 21% fly ash, and 21% GGBS. Such findings strongly suggest the positive influence of fly ash and GGBS in improving the resistance of bricks to ageing.

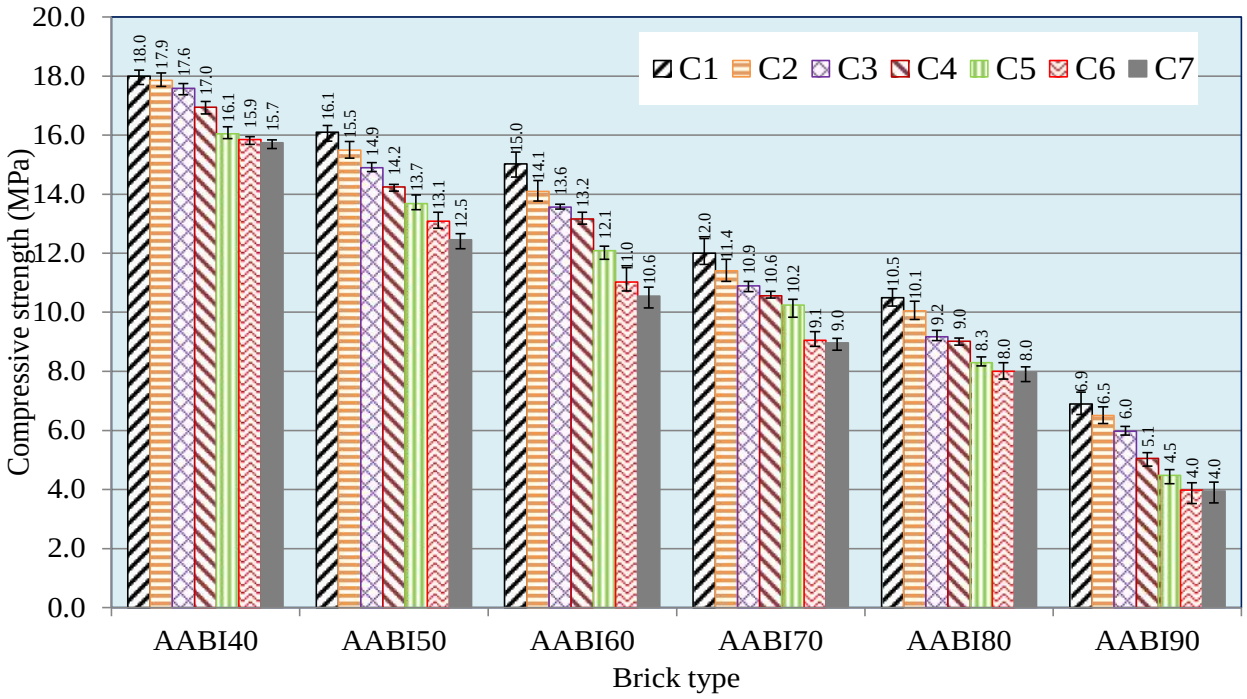


Figure 9: Compressive strength of bricks due to ageing test. (as per NBR 13544)

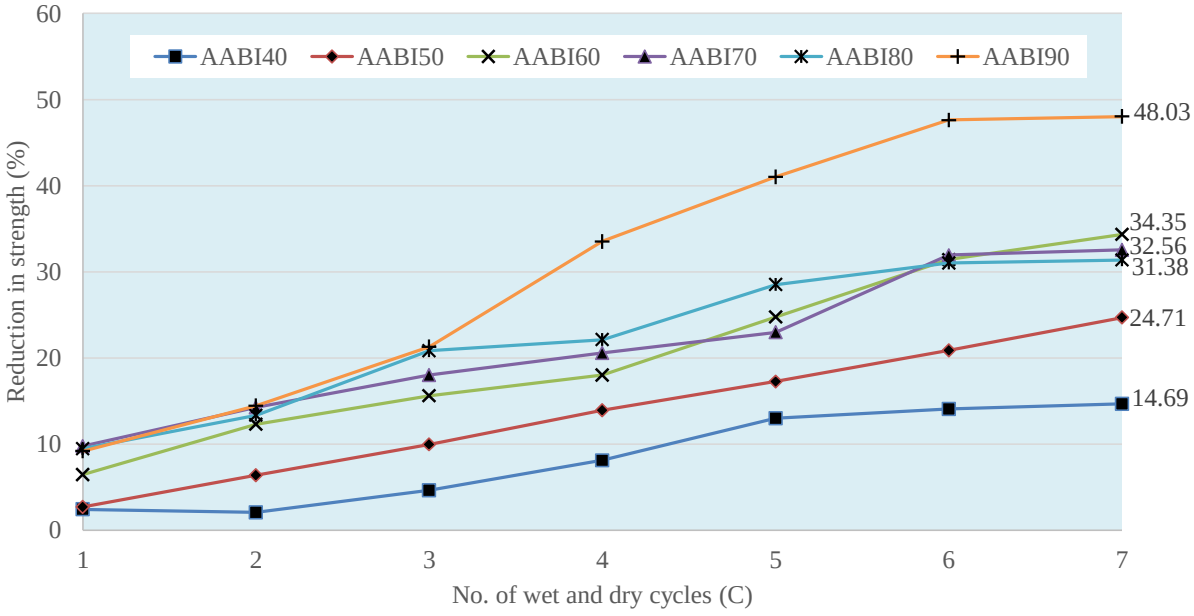


Figure 10: Reduction in compressive strength due to brick ageing

7.7 Prism test

Masonry prism test was conducted on the three prepared alkali activated composites which have 40% IOT, 60% IOT and 90% IOT with three different mortar strength of 3.5Mpa (week mortar), 6.5Mpa (intermediate mortar) and 15.5Mpa (Strong mortar). Totally 27 brick prism were tested to obtain compressive strength. Compressive load was applied on five brick high masonry prisms in UTM Approximate height of five-brick high masonry prism with 10 mm thick mortar joints was about 390-410 mm. The results obtained are tabulated in table 11.

Table 11: Masonry prism test results

Brick type	Brick strength (fb)	Mortar strength (fm)Mpa	Masonry compressive strength (fpm) Mpa
AABI40	18Mpa	15.5Mpa	4.89
AABI60	13Mpa		3.19
AABI90	7Mpa		2.98
AABI40	18Mpa	6.5Mpa	3.62
AABI60	13Mpa		2.98
AABI90	7Mpa		1.91
AABI40	18Mpa	3.5Mpa	3.40
AABI60	13Mpa		2.13
AABI90	7Mpa		1.70

With bricks containing 40% IOT (i.e. high strength brick 18Mpa) and week mortar (1:6) the prism was able to carry higher load upto 85kN with the maximum displacement of 7.72mm. With brick containing 90% IOT(i.e. weak brick 7Mpa) and high strength mortar (1:3) the maximum load carried was 40kN with the displacement of 2.48mm. Masonry with weak brick (90% IOT) was found to be less stiffer than that constructed with the other two types of bricks. Performance of masonry with intermediate mortar (1:4.5) and high strength brick (40% IOT) was much better than that of masonry with the other two mortar grades.

7.8 Cost analysis

Analysis of the cost in development of any product is an important parameter for the purpose of accounting, cost control, decision making and planning. An attempt is made to estimate the cost of manufacturing of the developed bricks. The cost of each item is based on the market survey conducted in and around the Bangalore region and is shown in table.12.The cost of manufacturing each brick in represented in table.13. The cost tabulated is for the manufacturing at the laboratory level excluding the transportation charges and also includes 15% extra as the manufactures profit.

Table 12: Raw material and man power cost

Particulars	**Rate**
IOT	0
GGBS	3 Rs/Kg
Flyash	1 Rs/Kg
Sodium Silicate	20 Rs/Lit
Labor charges	3 Rs/Brick

Table 13: Cost of each brick

Brick type	**Cost / Brick (Rs)**
AABI40	15
AABI50	14
AABI60	14
AABI70	13
AABI80	12
AABI90	11
42I-44G	10
52I-35G	9
62I-26G	7
42I-17G	6
72I-7G	5

Table 14: Compression of rate of construction with different bricks

Particulars (BxHxL)	Clay brick (110x70x 230)	Concrete block (100x200 x400)	Wire cut brick (110x70x 230)	Fly ash brick (110x70x 230)	Light weight bricks (100x200 x400)	Alkali activated IOT bricks containin g 60% IOT (110x70x 230)	Compres sed unfired IOT bricks containin g 62% IOT (110x70x 230)
Number of bricks required to construct one brick wall of 1sq.m	62	13	62	62	13	62	62
Rate for one brick (Rs)	8	32	14	8	45	14	7
Total cost of bricks used to construct 1sq.m wall	496	416	868	496	585	868	434
Rate for Exterior plastering /Sq.m(Incl uding labor) (Rs)	240	240	0	240	240	0	240
Rate for Interior plastering /Sq.m(Incl uding labor) (Rs)	210	210	0	210	210	0	210
Total Cost (Rs)	**946**	**866**	**868**	**946**	**1035**	**868**	**884**

Market study reviled the average cost of different bricks. It was estimated to construct one brick wall of $1m^2$ for different kinds of bricks and is tabulated in table.14. It was found that the cost of construction of the wall by the developed bricks were competent enough to fit into the current market value and can play the major role in the modern day requirements of the sustainable construction industry.

8. CONCLUSION

In the present study, compressed unfired IOT blocks stabilized with GGBS and lime and Alkali activated IOT bricks have been investigated. More emphasis is given on the potential of alkali-activated binders in developing bricks with mining waste IOT. Standard size bricks were synthesized with flyash, GGBS, IOT, and Na_2SiO_3 sol.

A series of laboratory tests were conducted to evaluate the strength of the bricks. Based on the experiments following important findings and conclusions can be enumerated.

1. Material characterization tests revealed that IOT had a large concentration of iron oxide with low silica content and the particle size of IOT was not uniform. This suggests that IOT contribution in the synthesis process will be minimal and it acts more like filler material.
2. The density of the unfired compressed IOT bricks and alkali activated bricks varied between 2.15 to 2.2 g/cm3 and 2.01 g/cm3 to 2.40 g/cm3 respectively, which is slightly higher than the conventional clay blocks due to higher specific of the IOT particles and also tight compaction during casting of bricks.
3. There is significant enhancement in the compressive strength of unfired compressed IOT blocks with incremental addition of GGBS. The best performance of 7.7 MPa after 28 days of curing was observed for block 42I-44 G. Such improvement can be attributed to distinct reaction between GGBS and lime with IOT, which provides better strength over time. Furthermore, it indicates the prospective of blended binders in development of stable IOT blocks. The compressive strength of Alkali activated bricks improved with the addition of fly ash and GGBS, and the best performance of 18.45 MPa was observed for brick type AABI40 which consists of 40% IOT, 21% fly ash, and 21% GGBS, along with 8% Na2SiO3 sol. and 10% water. The increase in IOT content reduced the compressive strength and the least performance was observed for brick type AABI90. However, bricks with up to 60% IOT meet the standard requirements of first-class bricks as per Indian standards, this suggests the prospect of alkali-activated binders in improving the recyclability of IOT.
4. The water absorption of 13% for 42I-44 G was the lowest among all other unfired compressed block types. This assures the positive interaction between GGBS, lime and IOT, which improves the compactness of the blocks primarily due to filling up of the voids with products of pozzolanic reaction and GGBS particles. Furthermore, lack of efflorescence for such blocks corroborates its practical feasibility. The water

absorption of all the alkali activated bricks was less than 20% and they satisfy the requirements for second class brick as per Indian standards. However, brick types AABI40 and AABI50 showed water absorption of less than 15% and classify as first class bricks.

5. The results of alkali activated bricks in the efflorescence test revealed that there was no efflorescence for brick types AABI40 and AABI50, while brick types AABI60 and AABI70 showed slight, and brick types AABI80 and AABI90 showed moderate and heavy efflorescence, respectively. Such findings corroborate the practical feasibility of developed bricks.
6. Based on the obtained results, the properties of the bricks will be significantly affected by the variation in physical and chemical properties of the source material; in particular, the characteristics of IOT need to be understood. Furthermore, it is interesting to see that with minimum addition of flyash and GGBS, and with Na2SiO3 as the only alkaline activator more than 40% IOT can be utilized in developing first class alkali-activated bricks at ambient conditions. This improves the practical feasibility of making alkaliactivated bricks with IOT and incurs environmental benefits over the energy-intensive methods of brick manufacturing such as firing.
7. Masonry with weak brick (AABI90) was found to be less stiffer than that constructed with the AABI40 and AABI60. Performance of masonry with intermediate mortar (1:4.5) and high strength brick (AABI40) was much better than that of masonry with the other two mortar grades (1:3 and 1:6)
8. Cost analysis made suggest that the developed IOT bricks have the great potential to fit into the competent market value to become the best commercial product.

9. The results discussed in the present study may be valid only for the low grade IOT. However, the proposed models are generalized and may be implemented for other regions with slight modifications in input parameters. Further experimental verification may be required for extension of these results for bricks made with IOT found in other regions, and mortar of different grades.
10. Finally, it can be concluded that with 8% Na2SiO3 as an alkaline activator and with the combination of fly ash and GGBS more than 50% IOT can be utilized to produce good quality bricks at ambient curing conditions.

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PUBLICATIONS

I. Papers in Journals

1. Compressed unfired blocks made with iron ore tailings and slag
   Thejas H K, Nabil Hossiney
   Cogent Enguneering. Vol.9, 2022.
   https://doi.org/10.1080/23311916.2022.2032975

2. Alkali-activated bricks made with mining waste iron ore tailings
   Thejas H K, Nabil Hossiney
   Case Studies in Construction Materials, Vol.16, 2022.
   https://doi.org/10.1016/j.cscm.2022.e00973

II. Conference Proceedings

1. A short review on environmental impacts and application of iron ore tailings in development of sustainable eco-friendly bricks
   Thejas H K, Nabil Hossiney
   Materials Today Proceedings.
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ANNEXURE

1. Journal paper-1

Thejas & Hossiney, Cogent Engineering (2022), 9: 2032975
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cogent engineering

CIVIL & ENVIRONMENTAL ENGINEERING | RESEARCH ARTICLE

Compressed unfired blocks made with iron ore tailings and slag

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Additional information is available at the end of the article

Abstract: Growing demand for houses in urban India has increased the requirements for construction materials such as clay fired bricks and cement blocks. At the same time, conventional practice of brick manufacturing is not environment friendly due to high energy consumption and CO_2 emissions during various stages of its production. Therefore, recent trend in research has been directed towards utilization of various industrial wastes and methods, which emerge as sustainable alternatives for environmental concerns arising in the construction industry. This study focused on utilizing mining waste, namely iron ore tailing (IOT) in development of stable blocks. It has reported various properties of compressed unfired blocks formed by IOT and ground granulated blast furnace slag (GGBS) in varying proportions and with a fixed amount of lime. The combination of GGBS and lime was found to be suitable in stabilizing IOT towards block production. Furthermore, a maximum compressive strength of 7.7 MPa was achieved for blocks after 28 days of air curing. Also, the addition of GGBS has reduced the water absorption and apparent porosity of the IOT blocks, confirming the positive interaction between IOT, GGBS and lime. It also indicates the prospective of blended binders in improving the compactness of the blocks, which will have direct influence on the durability and service life of the blocks. Finally, the results show that most of the developed blocks satisfy the requirement of IS 1077 specification and can be used in various applications such as load and non-load bearing walls, framed structures, foundations and pedestrian walkways.

2. Journal paper-2

Contents lists available at ScienceDirect

Case Studies in Construction Materials

journal homepage: www.elsevier.com/locate/cscm

Alkali-activated bricks made with mining waste iron ore tailings

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ARTICLE INFO

Keywords:
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Bricks
Iron ore tailings
Strength
Durability

ABSTRACT

In India, the enormous growth in the housing sector has put tremendous pressure on construction materials such as bricks. Conventional brick production methods include fired bricks and cement blocks. However, conventional methods significantly contribute to environmental carbon emissions and therefore alternative brick production methods have caught the attention of several researchers. Furthermore, the waste generated in various industries can be a useful resource for the construction industry, and in particular, voluminous waste is generated during the beneficiation stage of iron ore concentrate, which can be integrated into the construction industry to achieve sustainable practice. With this quest in mind, this study proposes the utilization of mining waste iron ore tailing (IOT) in alkali-activated bricks. For this purpose, six different brick compositions were synthesized with fly ash, GGBS, and IOT along with Na_2SiO_3 sol. The raw materials were characterized using various techniques such as X-ray fluorescence (XRF), X-ray diffraction (XRD), scanning electron microscope (SEM), and particle size analysis (PSA). Furthermore, a series of standard tests were conducted on the developed bricks to evaluate their strength and durability properties. The developed bricks have presented a maximum compressive strength of 18.45 MPa and minimum water absorption of 12.6%. Besides, the alkali-activated bricks have shown excellent resistance to brick ageing which was attributed to improvement in the microstructure of bricks due to the filling up of voids with products of the polymeric reaction. Finally, it was interesting to notice that with 8% Na_2SiO_3 as an alkaline activator and with the combination of fly ash and GGBS more than 50% IOT can be utilized to produce good quality bricks at ambient curing conditions.

3. Conference proceeding-1

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A short review on environmental impacts and application of iron ore tailings in development of sustainable eco-friendly bricks

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ABSTRACT

Increased mining activity of iron ore has led to the generation of voluminous wastes of various nature, especially during the different stages of its extraction and production. The improper disposal of such waste causes negative impact on the environment. One such waste which is generated during the beneficiation process of iron ore is waste iron ore tailings, which is also termed as IOT. Further, dumping of IOT on open ground creates huge dumping sites. This dumping sites have been a concern to the environment and human population in its close vicinity. Therefore, a need to effectively use IOT has become one of the subjects of interest for many researchers. This article provides a short review of environmental problems caused due to improper disposal of IOT, and also reviews on the reuse methods of IOT in the construction sector, which helps to alleviate the environmental pollution associated with improper disposal of IOT. Furthermore, reuse of IOT in construction sector reduces the exploitation of the virgin materials for production of construction material, and thus reducing depletion of natural resources. Based on the existing literatures and findings it was observed that the use of IOT to develop stable building blocks using unconventional methods showed great potential and improved performance, when compared with conventional materials such as clay fired bricks.

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4. Conference certificate-1